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Research Paper

Analysis of appropriate overtaking position under equal block lengths

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ABSTRACT

This paper studies train passing operation and determine line capacity by checking minimum headway. The analysis is based on the blocking time model displayed on the time space diagram where minimum headway and minimum waiting time are calculated. The study found that the capacity is affected by the number of blocks and the overtaking block position. The graph between the overtaking position and capacity is symmetrical, in which capacity is reducing when the overtaking position is far from the center of the line. The overtaking position that maximizes capacity is not affected by speed nor block length. In the case of even number of blocks, the appropriate location to overtake is (n / 2) +1 while in case of odd number of blocks, the overtake position is at (n+1)/2 and (n+3)/2. Both positions maximize the line capacity for each case. In addition, when the block length was reduced the capacity increased and decrease dwell time.

1. Introduction

Land transportation mode with the highest fuel efficiency is rail transport. It is 3.4-4.5 times more cost-effective than truck, 1.7-2.0 times cheaper than bus and 5.0 times cheaper than private car. It also releases lower greenhouse gas (Z. Wang et al., 2015). To cope with fuel crisis (Limanond et al., 2011; Travesset-Baro et al., 2016), pollution (Ó Gallachóir et al., 2009; Ratanavaraha and Jomnonkwao, 2015) and rapid increase in number of private cars (Mohamad and Kiggundu, 2007) governments in many countries set policies including car free day, car-restricted area (Nieuwenhuijsen and Khreis, 2016), public transport promotion campaign (C. B. Wang et al., 2011). Thai government also realizes and reacts on this concerns with focus on railway utilization. A large part of Thailand's railway network consists of single track sections. It provides low capacity due to limitations in passing and overtaking. The government recently initiated a double track program to increase capacity, shorten travel time and save the fuel energy used in transportation. Nonetheless double track construction requires high investment and takes a long time to implement. In the meantime, researches focuses on optimizing train schedule to accommodate trains on single track (Li et al., 2014). Some routes has successfully developed timetable for single track and accommodate a large number of passengers despite no investment for track doubling (Castillo et al., 2011).

Single track operation for trains with small speed difference will result in high capacity (Mitra et al., 2010). In reality, due to marketing reasons, passenger and

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freight trains must spread out operations to cover the whole 24-hour period. Slow and fast trains often run alternately. Timetabling must provide overtaking spots to increase the network capacity. This research explores the minimum headway for overtaking at different positions. It varies train speeds to determine relationship among overtaking position versus minimum headway, dwell time, and capacity. The best overtaking position will maximize the line capacity and best utilize single track infrastructure under given block length and schedule train speeds.

2. Literature Review

Researchers have employed many scheduling techniques to enhance utilities of the infrastructure. Previous studies include optimal rescheduling (Espinosa-Aranda and García-Ródenas, 2013; Törnquist and Persson, 2007) increase service frequency on single-track (Coviello, 2015), double-track (Xu et al., 2016) and mixed networks (Gao et al., 2016). These scheduling techniques take into account constraints on time components including departure time, running time, dwell time, and headway.

Single track scheduling normally focus on trains running in the same direction. The techniques include moving trains (Šemrov et al., 2016), adjusting time to enter the network (Carey and Carville, 2003) meet and pass at stations (Zhou and Zhong, 2007), and overtaking train by avoiding schedule conflicts (Pouryousef, Lautala et al. 2016), passing scheme where faster train gets priority (Dündar and Şahin, 2013; Heydar et al., 2013; Kanai et al., 2011; Krasemann, 2015), delaying slower trains at the station to accommodate faster ones (Barber et al., 2004; Chiang et al., 1998)

The change of the conflict position influences the delay of the trains (Li et al., 2008). Brucker, Heitmann and Knust find an optimal schedule with the minimal delay (Brucker et al., 2002). A different technique mainly focuses on reducing the running time per track section of different trains along a railway line (Vromans et al., 2006). Another study focused on minimizing the length of the dispatching cycle and minimizing the total stopping (dwell) time (Heydar et al., 2013). Optimization models are also used train scheduling problem of minimizing passenger waiting time (Niu et al., 2015).

Most researches go through trial and error process to determine the highest capacity or minimum safe headway. On the contrary, this research uses true minimum headway from blocking diagram model (Hansen. and Pachl., 2014) which vary by type of train, block length, and train length. It focuses on two types of train running alternately and in which faster passing slower trains. Minimum headway and dwell time are then determined from various passing scenarios

3. Materials and methods

3.1 Minimum Headway Analysis

Railway network capacity refers to the maximum number of trains passing a point in a given time period. It reflects rail service efficiency (UIC, 2004). The capacity greatly depends on train scheduling. The number of trains can be calculated from the reciprocal of average train headways. To increase capacity one needs to minimize the headway to the value by which train can follow one another safely under conditions of train speeds and block time model (Büker, 2013; de Fabris et al., 2014; Fumasoli et al., 2015; Hansen. and Pachl., 2014; Landex and Kaas, 2005; Medeossi et al., 2011; Pachl, 2002). Normal operating rule allows only one train to occupy a block to avoid conflict. Minimum headway analysis depends on determining blocking time which consists of running time, additional time need to clear the train and block. This clearance time consists of signal watching time (wt), clearing time in signal (ct), clearing time in block and release time (rt). Given V_i and V_j are the speeds of leading and following trains, the minimum headway analysis will consider three scenarios in which $V_i=V_j$, $V_i>V_j$ and $V_i<V_j$.

When the faster train follows the slower one, the minimum headway is larger than the other two cases. To avoid conflict, the fast train has to wait until the slow train reaches the destination and is taken out of the network. This research aims to minimize the headway when Vi<Vj to increase capacity and to determine the position that the conflict is most likely to occur. This position depend largely on speed difference (Törnquist and Persson, 2007) and block length. this study assumes that the faster train only pass the slow train once at a chosen location to minimize stops for the slow train (Goverde et al., 2016). Headway and dwell time can be determined from relationship between distance and train speeds on the critical block section (Goverde et al., 2013). If the passing occurs at block 3 (m=3) and block 4 (m=4) on a five-block section, the minimum headway (HW) and dwell time (DW) can be calculated as shown in Equation 1-6.

From relationship between overtaking position, speeds and block length in **Fig.1**, headway and dwell time for Trains *i* and *j*, when passing at *m*=3, can be determined as follows:

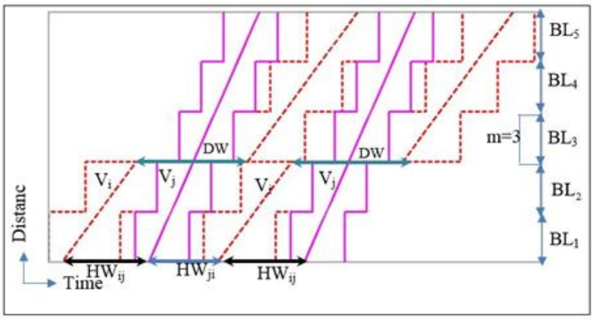

Fig.1. Time Space Diagram for Train i passing Train j in block 3

m=3

$$HW_{ij} = \frac{BL_1 + l_i}{V_i} + T_{FB} \qquad [1]$$

$$DW_i = \frac{2BL + l_j}{V_j} - \frac{BL}{V_i} + T_{FB} + HW_{ij} \qquad [2]$$

$$HW_{ji} = \frac{BL}{V_i} + \frac{l_j}{V_j} + T_{FB} \qquad [3]$$

From **Fig.2**, headway and dwell time for train *i* and *j*, when passing at *m* = 4, can be determined as follows:

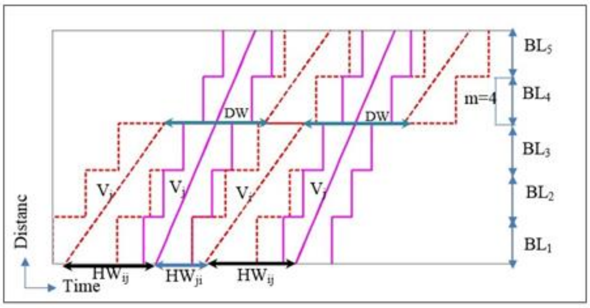

Fig.2. Time Space Diagram for Train i passing Train j in block 4

m=4

$$HW_{ij} = \frac{3BL + l_i}{V_i} - \frac{2BL + l_i}{Vj} + T_{FB} \qquad [4]$$

$$DW_i = \frac{4BL + l_j}{V_j} - \frac{3BL}{V_i} + T_{FB} + HW_{ij} \qquad [5]$$

$$HW_{ji} = \frac{BL + l_j}{V_j} + T_{FB} \qquad [6]$$

From the time space diagram in **Fig.1-2**, it can be seen that when the leading train is slower ($V_i < V_j$), the following train will need to overtake the first one. The minimum headway between trains *i* and *j* under an equal block length section can be determined as in Equation (7). The minimum dwell time can be calculated as in Equation (8), regardless of the overtaking position.

$$HW_{ij} = \frac{BL(m-1) + l_i}{V_i} - \frac{BL(m-2)}{V_j} + T_{FB} \qquad [7]$$

$$DW_i = \frac{2BL + l_j}{V_j} - \frac{l_i}{V_j} + 2T_{FB} \qquad [8]$$

When two type of trains run alternately in a given section, the headway of the third train which follows the second train can be determined from the overtaking position to avoid conflict between the two trains. Two cases need to be considered; (1) when passing occurs before the midpoint (m-1< n/ 2), and (2) when passing occurs after the midpoint (m-1≥ n/ 2). In the first case HW_{ji} depends on relationship between total section length and the overtaking bock as shown in Equation (9).

$$HW_{ji} = \frac{BL(n-2m+2)}{V_i} + \frac{BL(2m-n-1) + l_j}{V_j} + T_{FB} \qquad [9]$$

In the second case HW_j equals to blocking time of trains *j* as shown in Equation (10).

$$HW_{ji} = \frac{BL + l_j}{V_j} + T_{FB} \qquad [10]$$

3.2 Capacity Analysis

Capacity analysis takes into consideration the number of trains within the analysis period. In other words, the last train departs from the last block completely before time T (Abril et al., 2008). N example in **Fig.3** shows two type of train, i and j, running alternately where Vi < Vj in one hour. Trains of type i complete 6 trips and type j 6 trips. The capacity on this 5-block section is 6+ 6= 12 trips. The capacity can be determined as shown in Equation (11).

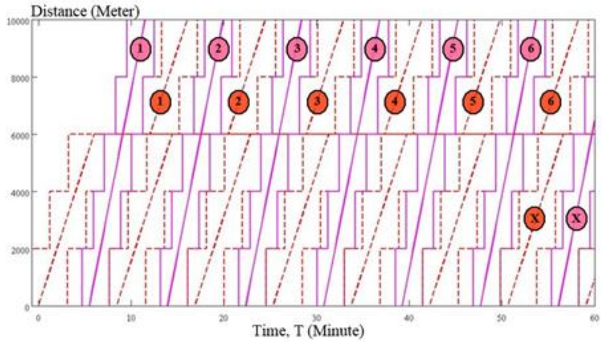

Fig.3. Consideration of trains which complete the trips within analysis period.

When Vi<Vj and passing occurs at block m, the capacity can be determined as

$$C = \frac{T - \dfrac{BL(n)+l_i}{V_i} - T_{FB} - DW_i}{HW_{ij} + HW_{ji}} + 1$$

$$+ \frac{T - \dfrac{BL(n)+l_j}{V_j} - T_{FB} - HW_{ij}}{HW_{ij} + HW_{ji}} + 1 \quad [11]$$

4. Results and discussion

The research results should be presented clearly and right to the point with accompanying figures and tables. These figures and tables should be referred to in the content. Explanation must not repeat what is already given in the content.

The study concludes that scheduling faster train to overtake slower one at any point of the section always reduce the minimum headway and increase capacity. Further conclusions can be drawn as follows:

4.1 Passing and Capacity

Scheduling fast trains to overtake slow ones increases line capacity. For example, consider train i with speed Vi = 60 km/hr leading train j with speed Vj = 100 km/hr in a 5 -block section**. Fig.4** show that capacity increase when dwell time of the slow trains i is extended to allow trains j to pass.

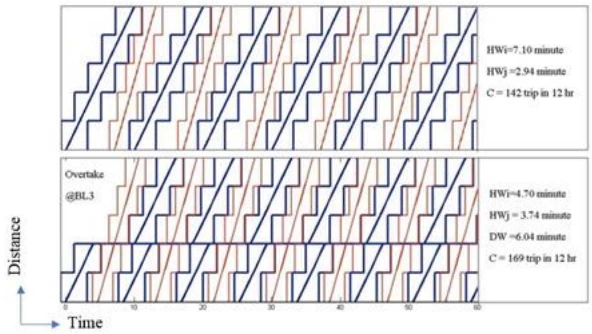

Fig.4. Comparison between following train and passing train schedules.

4.2 Overtaking position and Capacity

Capacity changes with the overtaking position. The overtaking position may be any block from the second to the n[th]. Capacity is identical between two symmetrical overtaking positions from both ends. For example, passing at block m = 3 and m = n-2, or m =4 and m = n - 3, will result in the same capacity value. The capacity increases when overtaking block is located near the midpoint, and is lower as the distance is farther away from it. The overtaking points near the beginning and the end of the section yields the lowest capacity, which is still higher than the following-train case. For example, **Fig. 5** show two leading and following trains running at 60 and 100 km/hr. When the second train passes the first at the 4[th] block the network achieve the highest capacity. This holds true regardless of speed difference.

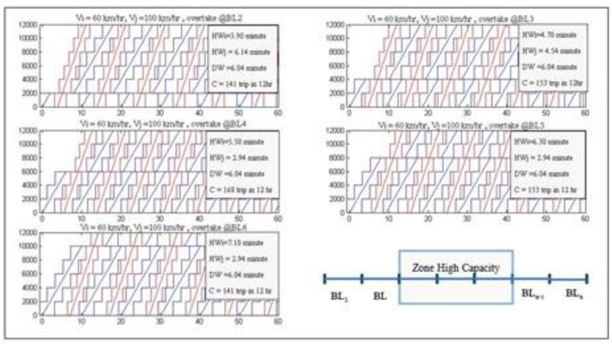

Fig.5. Train diagram showing effects of overtaking position to capacity

4.3 Number of blocks and capacity

The analysis of number of blocks in the section versus capacity uses the analytical equations as given above. It is finds that , in case of leading is slower than the following one, the best overtaking position is at (n/2)+1 with even number of blocks as shown in **Fig. 6** and at (n+1)/2 and (n+3)/2 with odd number of block as shown in **Fig. 7.**

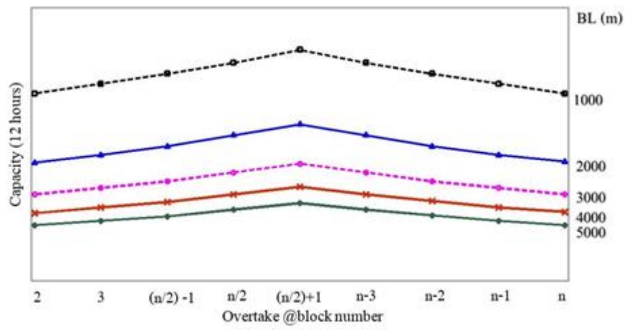

Fig.6. Capacity on the section with even number of blocks.

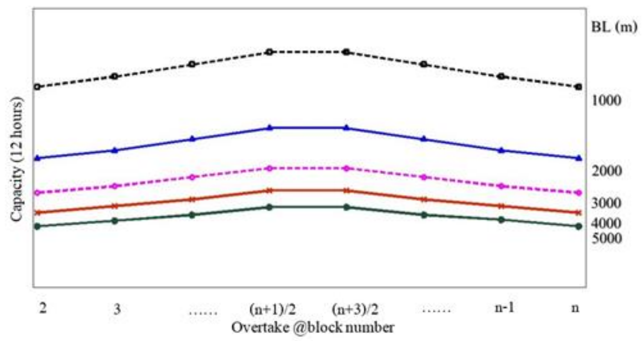

Fig.7. Capacity on the section with odd number of blocks.

In addition to overtaking position, block length also affect the capacity. If the block lengths are long the capacity is low (Dicembre and Ricci, 2011). Shortening block length increases capacity and directly reduce dwell time.

4.4 Speed and Capacity

Speed difference of the trains also affects capacity. The highest capacity is achieved when the same type of trains run together. The larger the speed difference, the lower the capacity. The high speed rail do not always yield high capacity, especially if it has to be operated on the same network with low speed ones. Heterogeneity of the trains greatly reduce the lone capacity in both following and passing schemes. **Fig.8** shows the first train with speed of 60 km/hr is released and the flowing train passes at the optimum position where the highest capacity is achieved. The following train running at 75 km/hr would result in higher capacity than those run with 100 or 155 km/hr. Although 155 km/hr train would be much faster, but it needs to keep large minimum headway due to safety reason.

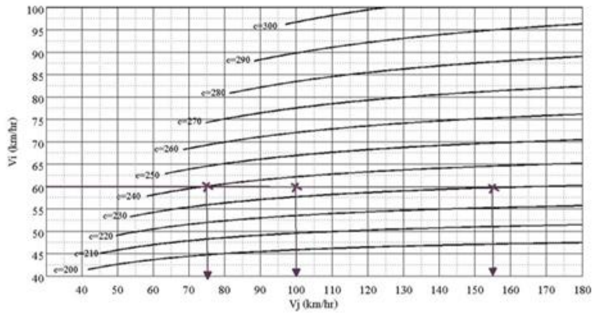

Fig.8. Relationship between Speed Difference and Line Capacity

5. Conclusions

Scheduling passing for trains with different speeds will improve the line capacity. On a section with equal block length, the only factor that determine the best overtaking position is the number of blocks. This position is not affected by speed nor block length.

Relationship between capacity and overtaking position is symmetrically linear. For example in the section with 6 blocks, overtaking position at 2nd or 6th block will result in the same capacity. As the trains only overtaking one another at the stations or sidings, the appropriate position to build these sidings should be the position that maximize the capacity (Higgins et al., 1997). The analysis suggests that when the number of block is an even number, the siding should be built at Block (n/2)+1. When the number of blocks is odd, the siding should be built at either block (n+1)/2 or block (n+3)/2. In addition to overtaking position, capacity also varies with the block length. The longer the block, the lower the capacity.

Speed difference affects minimum headway and minimum dwell time to let the other train pass. Trains with lower speed difference will result in higher capacity. High speed trains tend to lose capacity when running with very slow trains. The heterogeneous service consisting of express, rapid, local and freight trains should consider grouping trains with similar speed characteristics and assign appropriate overtaking block. Minimum headway should also be calculated to plan train release to enhance line capacity and best accommodate the passengers.

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